PRELIMINARY

ONBOARD CHECKOUT AND DATA MANAGEMENT SYSTEM (OCDMS)

Management Briefing Report

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LOS ANGELES, CALIF. WASHINGTON, D.C.

PRELIMINARY

This document was prepared by Planning Research Corporation under Contract No. NAS8-20367, "An Airborne Evaluating Equipment Study," for the George C. Marshall Space Flight Center of the National Aeronautics & Space Administration. The work was administered under the technical direction of Quality and Reliability Assurance Laboratory, Marshall Space Flight Center, with Walter T. Mitchell acting as project manager.

ABSTRACT

The purpose of this report is to provide a summary of the background of On-Board Checkout and Data Management Systems and the work accomplished under contract NAS8-20367 "Airborne Evaluating Equipment Study".

The background of development of On-Board Checkout and Data Management Systems is discussed in terms of its place in the general evolution of test and checkout operations. Work accomplished at the George C. Marshall Space Flight Center, at The Manned Space Craft Center, and by Aerospace companies performing work under government contract is summarized.

The On-Board Checkout and Data Management System studied under contract number NAS8-20367 is discussed in terms of the role of the system in the general mission, in terms of the system hardware requirements and in terms of the system software requirements.

The unresolved problems created by presently known mission requirements and the application of on-board checkout and data management systems to their solution is presented. Several deficient technology areas, in both technology and management techniques, are identified and related to advanced mission requirements. The report concludes with general conclusions and recommendations for continuing effort in this area.

TABLE OF CONTENTS

LIST OF EXHIBITS

INTRODUCTION

Reviewing the mission requirements for systems anticipated for the 1970's such as Voyager, The Saturn Apollo Application Program, and present concepts for manned-Mars orbital missions and Mars landing missions, we can conclude that we are entering an era in space vehicle technology. The nature of space vehicle systems and the missions which they are being called upon to perform are changing. The changes occurring fall into four categories:

1. The space/craft systems are becoming more complex. This complexity is not needless complexity but rather complexity dictated by increasing mission requirements.
2. The system operating times are increasing by several orders of magnitude. The significance of systems test and checkout operations performed over time periods which are several orders of magnitude less than the operating time period is decreasing.
3. The distances traversed by the operating space vehicle system are increasing significantly. This results in increased performance requirements for the space vehicle communications system.
4. The objectives of each flight or mission is becoming one of scientific experation. We are now more concern-

ed with developing systems that "earn their keep" than with gathering information permitting us to develop better systems.

With these new and more demanding mission requirements comes increasing demands on all phases of spacecraft development and operation. But also, and possibly to a greater extent, new demands will be placed upon technical management methods and techniques.

This report is concerned with vehicle systems test and checkout and the methods of approaching this operations in such a manner as to meet the performance requirements of these future space vehicle systems.

The work discussed in this system is concerned with On-Board Checkout and Data Management Systems (OCDMS) in two types of spacecraft; manned spacecraft and complex unmanned spacecraft. The work done did not, and could not, provide justification for implementation of OCDMS on any spacecraft system.

The justification for any vehicle born system is to be found only in the manner to which it contributes to the performance of the mission or to the probability success of the mission. The decision as to whether or not a system is to be implemented into hardware and to be carried by the vehicle system is reached on the basis of comparing its performance contribution and/or its contribution to probability of success, or reliability, to the cost of its implementation. The question that must be answered is then "How does OCDMS contribute to performance or success of a mission?"

An On-Board Space Vehicle System capable of performing a complete systems test and checkout operation must, due to the nature of the systems checkout operation, be capable of excerising control over the total system and/of measuring the responses of that system to the control actions. An On-Board Checkout System can thus be regarded as being also an On-Board control and data management system.

The natural tendency is then to regard the system as three distinct functional systems and to attempt to find justification for each function independently of the others. This is an incorrect procedure but one that is almost implicit in organizational and management divisions of responsibility that exist today.

Present organizational and management techniques encourage the design engineer to consider control operations without significant regard to either checkout requirements or data management requirements. Similiarly, those persons concerned with the data handling processes involved in instrumentation and telemetry systems do not usually consider the control requirements or the requirements of test and checkout in the development of their systems.

If the on-board checkout system were considered without regard for control and measuring functions, the system could provide an increase in the proability of successful operation of the system only thus:

1. In the case of the complex unmanned spacecraft, justification for the system would depend primarily upon the improvements in operations prior to launch and upon the possibility of gathering information from the independtly designed checkout systems to enable the independently designed system to overcome some system malfunction.

2. Justification for an on-board checkout system in a manned spacecraft would primarily depend upon providing adequate information for detecting malfunctions and enabling corrective action to be taken in maintenance operations by the on-board personnel.

If we modify some past management and technical practices which dictate this separation of control systems, measuring and data management systems, and checkout system development and implementation and if we have a simultaneous and interative development of an integrated on-board control, checkout, and data management system for a specified mission, complex unmanned or manned, it might be possible to produce both a significant increase in performance and a significant increase in probability of successful operation. This increase in performance capability and probability of success of the mission through the development of an OCDMS system and its implementation cannot be specifically shown without defining a specific mission as we have stated before. The objective of this report is to provide sufficient information to experienced readers to permit them to estimate the potential value of such systems in general terms.

I. BACKGROUND OF ON-BOARD CHECKOUT AND DATA MANAGEMENT SYSTEMS

A. Review of Development of Vehicle and Checkout Systems Communications Methods

The driving force behind change in space vehicle systems design is an interaction between available technology and increasing mission requirements. On-Board Checkout and Data Management Systems are a logical evolutionary step, not a revolutionary step, in the continuing improvement of our technological ability to meet increased mission requirements.

If we look back on the history of communications between vehicle systems and checkout systems, we find three phases in vehicle/ground communications development.

The first phase, occurred in the early and mid 1950's. Communication between the ground checkout equipment and the vehicle system, in such systems as Redstone, Viking, and Jupiter, was accomplished through a number of interfaces. These interfaces were umbilical plates, ground disconnects, special checkout harness installations, and flexhose installations which were installed into the vehicle system for checkout. These various vehicle interfaces were in turn interfaced with manual checkout equipment performing test and checkout operations which consisted of essentially static point test and checkout.

In the late 50's, such systems as Bomarc and Atlas were developed. Checkout systems for these vehicles still relied on umbilical plates and ground disconnects, checkout harnesses, and flexhose installations for obtaining signals and dispensing control actions to the vehicle system. The ground equipment was still essentially manual equipment but sequence devices based on developing digital technology found their first applications. Continuing development of these checkout systems into the early 60's was accompanied with an increased utilization of digital technology.

In the early 1960's, with the advent of the Saturn/Apollo vehicle systems, we have entered a new phase in vehicle/ground checkout communication systems. In checkout today, we still find umbilical plates and ground disconnects being used, but we find a considerable decrease in the amount of special purpose checkout installations in the vehicle system. We find a significant amount of highly developed ground switching and control systems supplemented by, and working with, ground-based checkout equipment and computer systems. Further, for the first time some vehicle-borne checkout assisting devices, which developed in consequence to mission requirements, are being used in systems test and checkout. These systems are exemplified by the RACS System, and DDAS Systems.

OCDMS represents the fourth phase in the logical development of these communication capabilities between the vehicle and ground systems. The technology developed over the last several years, and the mission requirements implicit in such systems will be operational use by the early 1970's. When

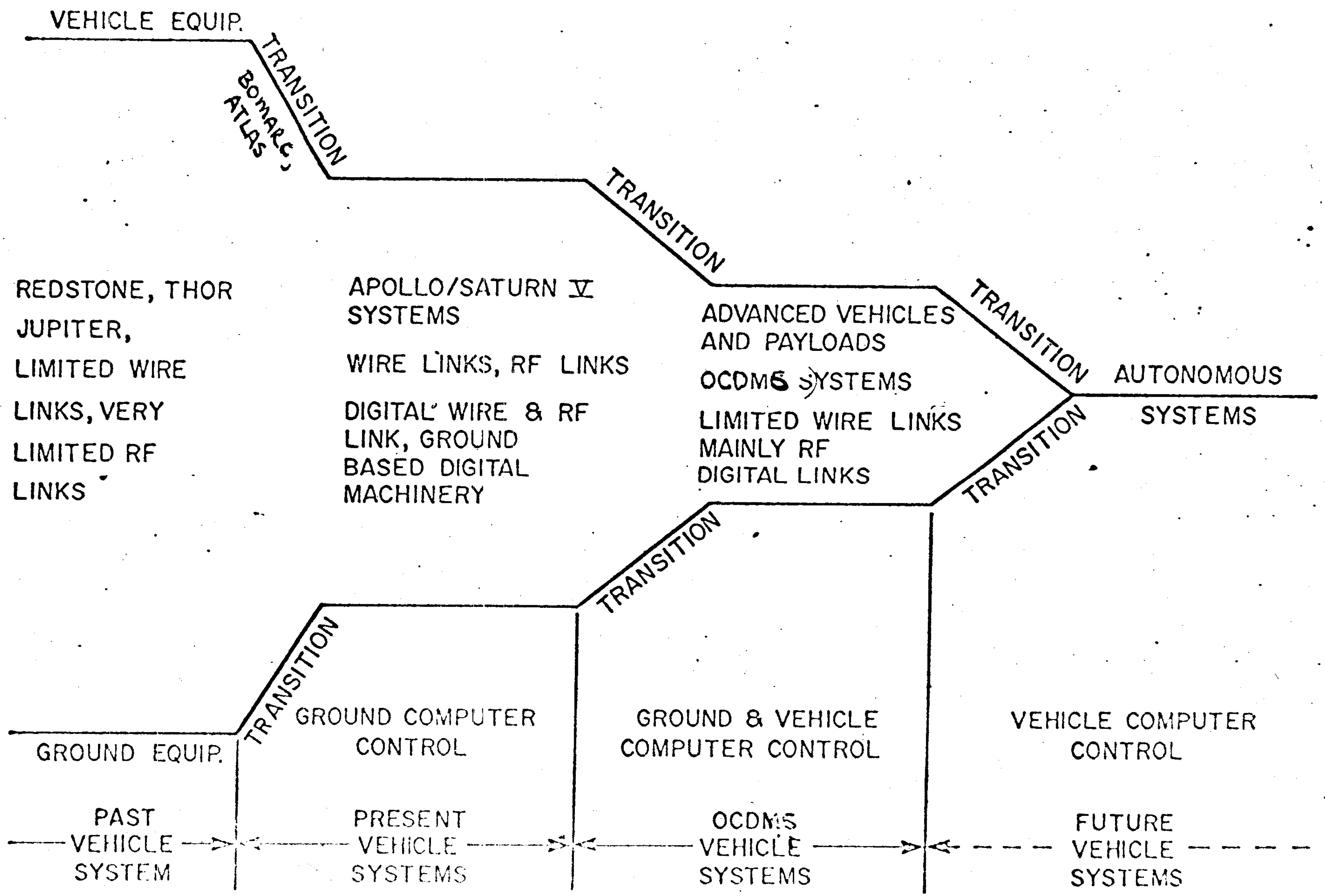

EXHIBIT 1- THE DECREASING TREND IN VEHICLE/GROUND COMMUNICATION BARRIERS

compared with previous methods in vehicle ground communication, the OCDMS approach is characterized by a system requiring no umbilical plates or ground disconnects as we know them (except for power) no special checkout harnesses, etc., and significant use of vehicle instrumentation and control systems. Communication between this vehicle-borne system and ground-based system, in its ultimate configuration, will be accomplished by R. F. and Coax links.

B. Accomplishments to Date in the Area of OCDMS Development

1. Work Accomplished at The Marshall Space Flight Center

Three studies related to OCDMS systems were performed by the Quality and Reliability Assurance Laboratory and Aerospace Companies under contract to MSFC. These studies were performed by the Lookheed Missiles and Space Company, The Boeing Company, and the Quality and Reliability Assurance Laboratory, Vehicle Systems Checkout Division, Advanced Systems Engineering Section working with SPACO, Inc.

a. The Lockheed Corporation, under Contract No. NAS8-11477, undertook a study addressed to two general problems:

Problem 1

Determine which elements of classical post-manufacturing checkout require change or addition for accommodating the peculiarities of orbital operational stages.

Problem 2

Analyze the problems of control of automated checkout of Saturn stages.

The tasks performed under this contract consisted of the following:

Task A:

o Define how factory checkout of the Saturn orbital stages could be improved without significant change in methods or hardware.

o In future generations of Saturn orbital stages, define what requirements of orbital checkout should be considered during the design phase so that decisions to continue the mission, select an alternate mission, or abort the mission from a parking orbit, may be based on adequate and accurate information.

o Determine what changes in the planning and conducting of manufacturing checkout must be made to verify the orbital checkout capabilities of the stages.

Task B:

o Review existing designs of stage checkout equipment for the Saturn S-I, S-IB, S-II, and S-IV.

o Derive all types of checkout information existing in the system, determine what is available to the text conductor and what is actually useable by him.

o Consider all possible methods of extracting this information, predigesting it as necessary, and presenting it to the test conductor.

o Similarly consider various methods of control and their utility to the test conductor.

o Develop the requirements for a system of preferred display and control. Give consideration to compatibility of existing checkout and launch site display equipment with these requirements.

o Describe typical methods of display and control including single-line block diagrams, verbal descriptions of their functioning as individual blocks and as a whole, appropriate sketches of panels to be used and indication of how these systems might tie into existing systems.

o Perform computer flow diagramming (but not actual programming) required for use of the recommended system.

o Devise experiments that can demonstrate the utility of the suggested concepts and methods of the display and control.

ANALYSIS OF CHECKOUT WITH MINIMUM HARDWARE CHANGES

Three specific checkout operations were studied:

- o S-IVB Simulation of Orbital Checkout During Post-Manufacturing Checkout (Section 2.1).
- o Post-Manufacturing Test of the Instrument Unit (Section 2.2)
- o Flight-IU Mated with S-IVB for Factory Checkout (Section 2.3)

The premise of these studies was that no changes would be made to existing designs unless (1) they would appreciably aid in performing checkout and (2) they could be incorporated without any impact on schedules and with a minimum increase in weight or cost.

Findings with Minimum Vehicle Changes

It was concluded that the present configuration of the Saturn S-IVB limited the amount of orbital checkout that could be performed on the vehicle. As a result, orbital checkout would be essentially equivalent to Agena practice and limited to the following areas:

- Determining status of significant components such as valves and relays to insure that the vehicle is in the desired condition
- Evaluating engine performance in real-time during first burn to establish the specific impulse realized during that phase
- Determinating the remaining expendable stores to insure mission completion
- Operating the engine gimablling system to determine its responses
- Checking of proper timing and sequencing.

ANALYSIS OF CHECKOUT WITH DESIRABLE MAJOR CHANGES

S-IVB Stage

The existing S-IVB stage is satisfactorily designed to permit factory checkout with the use of computer-controlled checkout equipment; however, this stage design severely limits the amount of orbital data that could be secured.

These limitations stem from the following reasons:

- o Some equipment cannot be operated without creating an undesirable condition for orbit.
- o Equipment must be kept in a state of readiness so that is may be operated to maintain proper orbital status.

Findings with Major Vehicle Changes:

The following was concluded:

- o Orbital checkout is best performed by an on-board checkout system with self-contained controlled-stimuli generation and distribution, and data collection and analysis.
- o It is as important to predict future operationsl integrity of the equipment as it is to determine the current status.
- o Extending beyond the present concepts, the following would bring the confidence in orbital checkout to the equivalent level of present ground checkout:
    1. Provision for subsystem maintenance, repair and resupply
    2. Provision for replenishment of expendibles, such as gasses, fluids, cryogens, etc.
    3. A sizeable increase in component reliability required by the increased stay time in orbit.

It was recommended that the following modifications or additions be incorporated in the existing stage design:

- Install fluid mass sensors suitable for use under zero g. These snesors are necessary for the evaluation of engine performance, integrity of insultation and propellant storage, and controlling and monitoring of replenishments.
- In the propellant and valve control systems, incorporate valves with Transit time, or breakaway load sensors, which can provide information from which significant changes in operational characteristics can de deduced.
- Add sensing devices so that each part of the quadruple-redundant attitude-control unit valves can be evaluated.
- Use programmable multiplexers in the telemetry system prior to encoding in order to provide flexibility in checkout scheduling and data readout.
- Improve on-board diagnostic capabilities, as typified by the error phase plane comparator.
- Provide 12,000 words of LVDC instruction memory for error phase plane comparisons, and for control of the remote programmable multiplexers in the S-IV and IU.

b. The Boeing Company, under Contract No. NAS8-20240 performed a study with elaboration of the Lockheed Study results. The Boeing Company proposed a particular hardware configuration for on-board checkout of the S-IV and IU stages of the Saturn V.

The basic system componets of the Boeing concept are shown in Exhibit 2. The blocks designated "PTU" represent the Boeing hardware. PTU stands for Peripheral Test Unit. Each PTU can apply stimuli to various points in the stage, measured values against pre-determined upper and lower limits for an out-of-tolerance condition. This stimuli-application/ response-measurement/limit-comparison process is controlled by a set of instructions stored on a magnetic tape unit integral to the PTU. The PTU also has a programmable delay feature to ensure accurate measurement and correct sequencing.

Boeing proposed three PTU's: one in the IU, one in the forward skirt area of the S-IVB, and one in the aft skirt of the S-IVB. The LVDC/LVDA in the IU was proposed as the central controller for all three test sets. The LVDC/LVDA is, in turn, controlled by the ground checkout computer system.

A normal sequence of events might start with a test controller on the ground requesting a test via his console. The ground computer system would then transmit the test identification to the LVDC, which would send it to the appropriate PTU. Upon receipt of the test ID in the form of a command from the LVDC, the PTU magnetic tape would be automatically searched until the desired test was found. The PTU would then execute the test in accordance with the magnetic tape instructions. Whenever it had data or GO/NO/GO information, the PTU would interrupt the LVDC and transmit the information. the LVDC would then relay the information back to the ground for the benefit of the test controller.

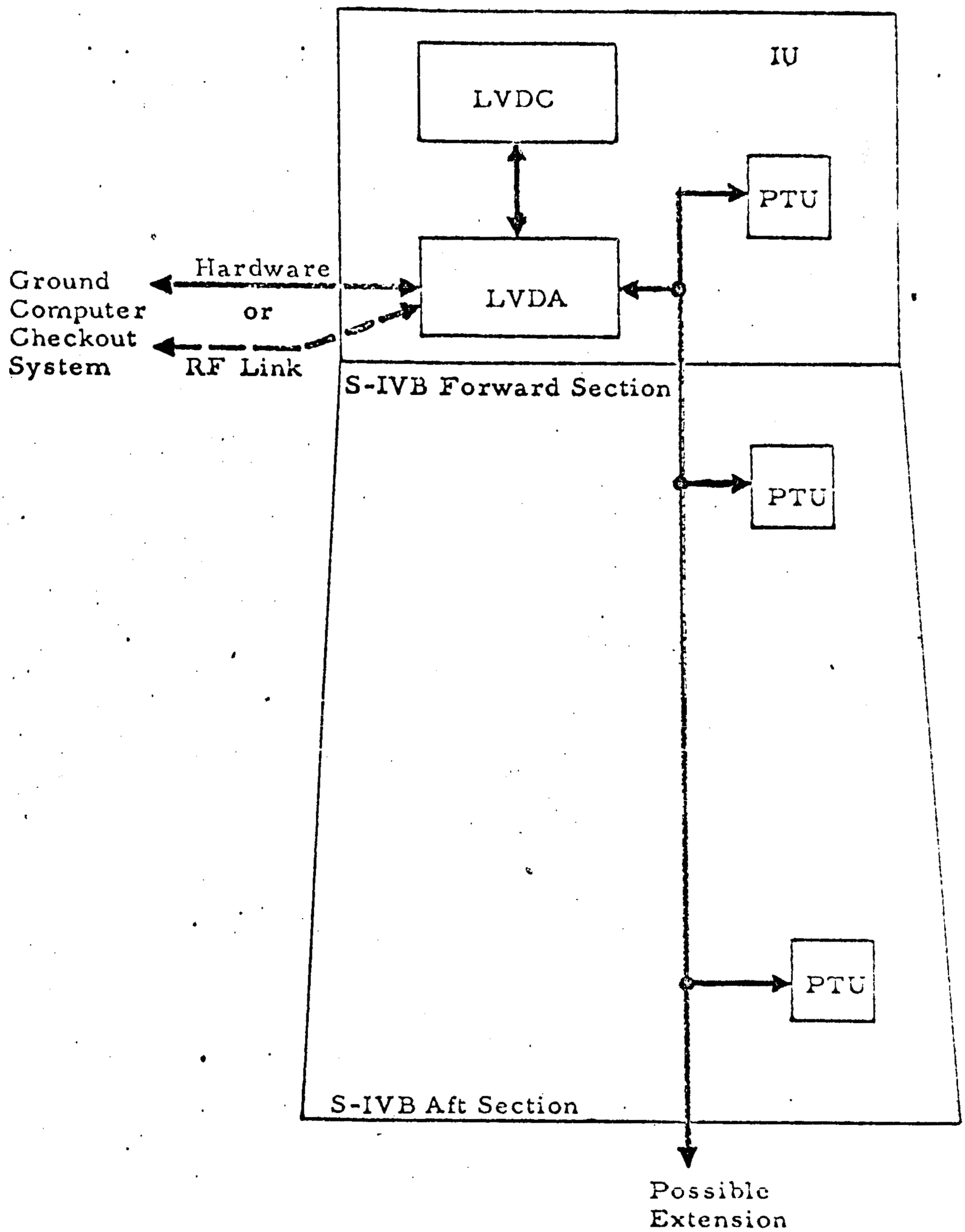

EXHIBIT 2- BOEING AEE CHECKOUT SYSTEM BLOCK DIAGRAM

Primary control of test operations resides in the ground checkout system. The ground system can request a complete test, a single measurement, or can effectively take the place of the magnetic tape and specify each PTU operation. In addition to the programmable portions of the PTU, there is a hard-wired monitor system for emergency-condition detection.

In terms of the hardware only, the most desirable features of such a system are the elimination of ground-to-vehicle umbilicals and increased orbital checkout capability. With such a system, the operation of the vehicle can be checked out on-board and the results relayed to the ground via the LVDC-ground system link. This eliminates the need for a wire from the ground to each point to be measured, monitored, or controlled.

The presently planned telemetry system is unaffected by the Bowing hardware. The Boeing system was designed with future expansion ot other stages and the spacecraft as a possibility. via addition of PTU's in those stages. However, this expansion is limited by the separation of the IU and S-IVB first from the vehicle stages and later from the spacecraft. Although AEE was analyzed for use with LEM and AAP experiments, the Boeing work did not include these areas.

Findings with The Boeing AEE Concept:

A great many problems have been discovered in studying implementation of the Boeing system. It is important to distinguish between problems caused by the study guidelines, problems caused by the concept of any on-board system, and problems which the PTU's themselves uniquely cause or aggrevate.

The objective of minimizing the disruption to the current operations causes many problems. It was clear that any on-board checkout system which is to be utilized for the entire vehicle, or at least large portions of it, will cause significant changes to current operations and current operational philosophy.

Although it was not stressed in this study, there is a requirement that AAP vehicles be scheduled intermixed on a noninterfering basis with Apollo vehicles. The above-mentioned changes to the ground systems and the different stage hardware configurations would make this type of scheduling difficult. Rapid changeover from an AAP-to an Apollo-configured ground system may prove infeasible. Similarly it may not be possible to produce the intermixed stage hardware on a single production line.

A second problem that follows from AAP application is the provision of PTU control after separation of LEM and IU. An LVDC substitute would need to be provided on LEM (for experiment checkout) and access provided to it through the LEM PCM system.

This study did not attempt to fully investigate problems that might be associated with any on-board checkout system rather than just the PTU concepts. The study was devoted to the PTU problems in particular. Nevertheless, it is possible to draw some conclusions about the relative ability of the PTU concepts to meet the design objectives as compared, for instance, with a general-purpose on-board checkout computer system.

The PTU's lack the processing and decision-making capabilities that characterize a general-purpose computer. It is largely for this reason (and the lack of a working storage memory on-board) that the PTU test programs must be so tightly interwoven in the form of the PTU Test Table with the ground systems. It may be possible with a more powerful on-board system to achieve a much greater degree of independence from the ground. One possibility is to permit the on-board system to a large extent to control the ground system. This possibility is not open to the PTU's because of their restricted capabilities. The PTU is designed for applying a stimulus, measuring a response, and determining out-of-tolerance conditions--and very little else. Hence, the housekeeping activities of the present checkout system, such as maintenance of status files, is beyond the scope of the PTU's.

While this study has not tried to determine how well the design objectives could be met by more powerful checkout systems, there seems little doubt that much more could be done than the Boeing system envisions. Presumably the Boeing system offers economy over a more powerful system, but in the long run the difficulties of utilizing the PUT's make these economies questionable. Certainly it can be recommended that a very intensive examination be conducted prior to any actual mechanization of the Boeing PTU concepts.

SPACO, Incorporated Study:

Spaco, Incorporated, under supervision of MSFC, Quality and Reliability Assurance Laboratory Personnel, performed a study of the MOLAB System based on the assumption that the MOLAB System would have to be capable of remote automatic systems checkout.

The primary objective of this study was to determine and document the post-manufacturing checkout plans and requirements for the systems of the Lunar Mobile Laboratory (MOLAB). The second major objective was to investigate the MOLAB requirements for hardware that would facilitate and permit a comprehensive manufacturing checkout of the MOLAB vehicle.

The checkout systems incorporated provisions for monitoring and analysis of critical system functions in such a manner that out-of-tolerance performance would be recognized, and assessed, both on the ground, inflight, and on the lunar surface, using on-boarc equipment, in time for remedial action. No equipment used solely for pre-launch testing was to be installed aboard the spacecraft as fly-away hardware unless an overall program saving could be demonstrated. Test equipment installed aboard the MOLAB as fly-away hardware was compatible with all equipment used in the several phases of checkout.

These specific objectives were used to provide a basis for the MOLAB Post-Manufacturing Checkout Study. Configurations

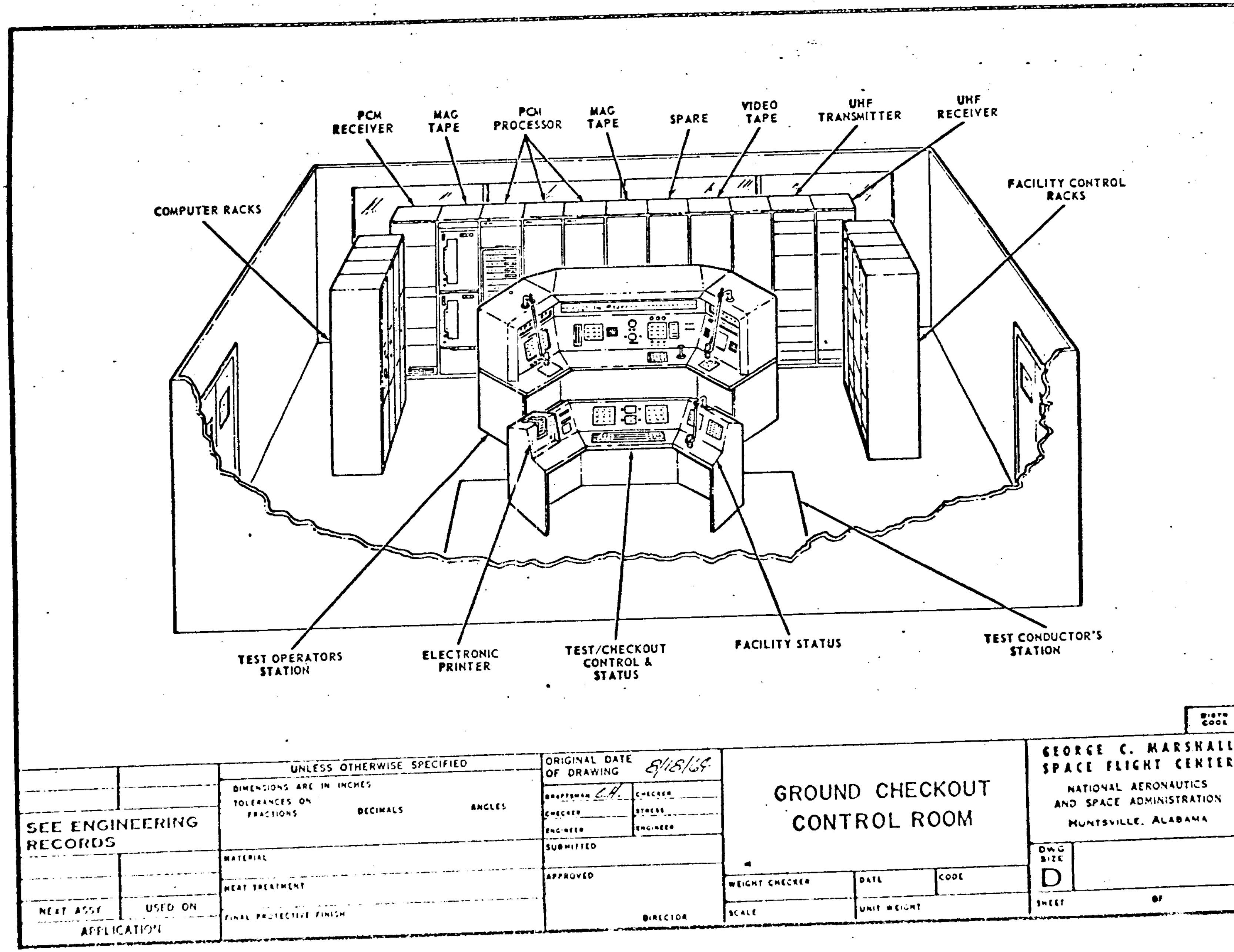

EXHIBIT 3- MOLAB COMPLETE GROUND CHECKOUT CONTROL ROOM

of the MOLAB systems and subsystems were specified, within the realm of feasibility, so that checkout hardware, techniques and methods could de developed for the specified systems. The goal was to develop a checkout system that was capable of a comprehensive factory checkout operation, whcih could be performed both remotely and automatically.

Findings

This report shows that only a modest amount of additional hardware was required for checkout when checkout provisions were included in the basic MOLAB system, subsystem or component design. In many cases, control equipment or operational sensors, that were required for normal system operation, sufficed for response evaluation during factory checkout when checkout was considered from the start of design.

2. Work Accomplished by MSC

The Martin Company, Denver, Colordad, is presently in the final phases of a technical program investigating on-board checkout systems.

The technical portion of the Martin OCS program consisted of six major phases. These are: (1) determination of checkout requirements; (2) selection of a concept to meet the requirements; (3) development of the system design based on the selected concept; (4) supplying of a breadboard model to prove the feasibility of the design; (5) preparation of technical results which consist of sensitivity matrices to define the impace of individual requirements on OCS weight, volume, power consumption, and reliability, a self-check tradeoff model to compare the use of OCS (a centralized checkout system) with the concept of building self-check into each AAP experiment or developmental subsystem; and (6) an implementation phase. The breadboard was delivered and a formal demonstration was dame on 25 February 1966.

The objectives of the technical studies for the OCS were:

a) Determine the requirements for an OCS for the AAP program;

b) Select a design to fulfill the requirements;

c) Perform detail design of the selected system to a depth necessary to produce the technical outputs;

d) Produce hardware specifications, software specifications, interface specifications, a self-check trade-off model, and a sensitivity matrix;

e) Produce a feasibility breadboard to support the system concept and supply computer programs necessary for breadboard operations.

Before a detailed analysis of the objectives was made, certain ground rules were established. Some of the major rules affecting the system design are:

a) The OCS will check out, monitor, and perform malfunction isolation of all systems under test but will be constrained to electrical stimuli and measurement interchanges with these systems;

b) The OCS will be capable of operating independently of earth, i.e., self-sufficient within a manned spacecraft;

c) The OCS must be capable of being under complete control of ACE-S/C and GOSS and allow complete checkout evaluation from these systems. This includes self-check of the OCS;

d) OCS will have the capability to perform checkout at various stages of spacecraft activity from factory through mission;

e) Flight missions up to 45 days duration must be considered;

f) No additional carry-on PCM will be required;

g) Basic power for the OCS will be derived from the AAP laboratory module power system;

h) The OCS configuration will be such that it may be adapted to a particular spacecraft and experiment mix, i.e., it shall be modular in form;

i) The following physical characteristics, defined as major goals, will be used as a guide during the study,

Weight (including expendables of spacecraft fuel cells supplying OCS power).	150lb,
Reliability	0.995,

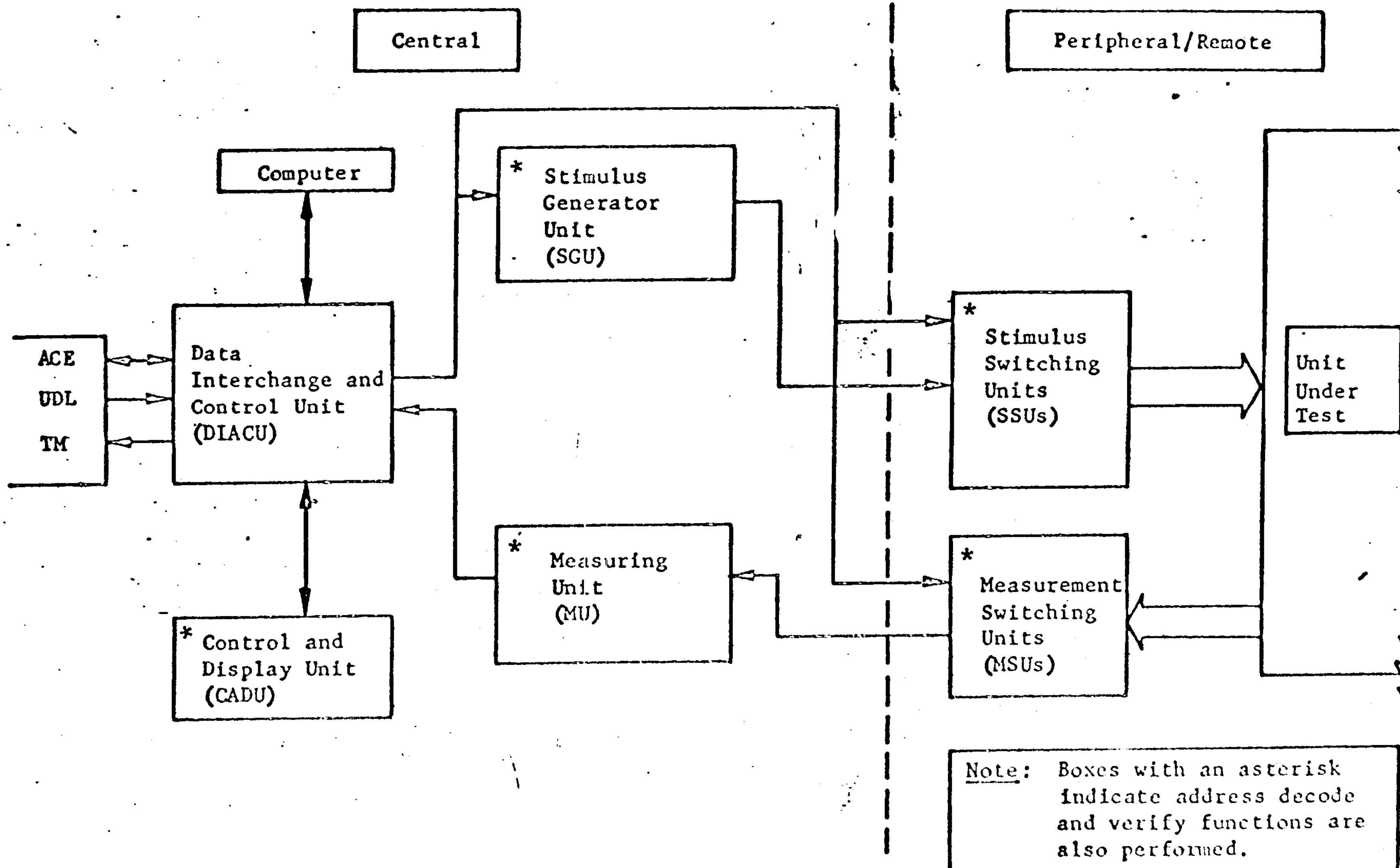

EXHIBIT 4- MARTIN COMPANY, OCS BLOCK DIAGRAM

Availability	18 mo,
Power	450 w.

Findings:

The objective of this study was to define an On-Board Checkout system while working under some general constraints. No major conclusions as to the desireability of implementing the program were drawn as this was not an objective of the study.

3. Progress made in the area of On-Board Checkout and On-Board Checkout and Data Management Systems by The Aerospace Industry:

An extensive literature search was performed by the IBM Federal Systems Division in December of 1960 on the subject of On-Board In-Flight Checkout. The study was performed for the AirForce Aero-propulsion Laboratory at Wright Patterson Base, Ohio, and included published reports, symposia, technical journals, and magazines. Emphasis was placed on documents issued after 1961, because a similar literature search had been conducted by the Battelle Memorial Institute covering the pre 1962 time period. The study included literature on the following subjects:

a. Automated checkout of any aircraft, spacecraft, or missile system

b. Digital checkout techniques

c. Fault isolation

d. Trend analysis and failure prediction

More specific references related to progress being made in the industry in the area of general automatic checkout systems and on-board checkout systems can be found in the 1965 and 1966 Automatic Support Systems Symposiums Proceedings sponsored by the Institute of Electrical and Electronic Engineers, St. Louis, Missouri, Section.

The conslusions that can be reached from the present literature are:

a. The work being performed by the Manned Spacecraft Center and the Marshall Space Flight Center represent the most detailed analysis performed on complete NASA space vehicle systems On-Board Checkout Systems and On-Board Checkout and Data Management Systems at this time.

b. The work being performed for the MOL program by the USAG is oriented toward a system functionally similar to OCDMS as discussed in this report. Work on this project has passed the preliminary design phase and is presently entering the design prototype phase.

c. Many of the technology areas unique to on-board checkout systems and on-board checkout and data management systems have been studied by various companies and agencies. Their studies however, have been limited to general considerations of the problems, development of possible methods of approach to solution of the problem, and hypothetical extrapolations of the applications of existing methods to these classes of problems.

D. A significant amount of technology is available in the hardware area and the assembly of this technology for application to actual development of such a system would probably not present a difficult task. This applies particularly to the development and present availability of extremely powerful micro-circuit airborne computer systems.

II. The On-Board Checkout and Data Management System Study performed by the Planning Research Corporation

The Planning Research Corporation, under contract No. NAS8-20367 to the Vehicle Systems Checkout Division of Quality and Reliability Assurance Laboratory, has performed a study to define the requrements of, and do conceptual design of, an on-board checkout and data management system.

At the start of the study, after review of documentation resulting from previous study efforts by other contractors, it became apparent that; in order for the study to produce satisfactory results, the problem would have to be studied in significant depth. Real operational requirements and the methods of achieving their solutions would have to be developed in greater detail than have been developed by any previous investigators. This in turn required that some specific hardware system and its associated mission requirements be studied. The "Study Vehicle" selected was the Saturn/Apollo Applications Program Experiments Subsystem. This system was selected because of its technical pertinence and because of the availability of adequate documentation to support the level of analysis required.

Initial investigations were pursued on the basis that only an on-board checkout system would be required. As the study developed, it became more apparent that the system would also be inherently capable of performing significant data management duties and other functions. The study was then redirected to approach the problem of On-Board Checkout and Data Management

Systems (OCDMS) for use on a Saturn/Apollo Applications Program Experiment Subsystem. The depth to which the study if being pursued is best represented by the technical documentation to be delivered. These end products consist of the following:

1. General Specifications for performance and design requirements for OCDMS
2. Part I CPCEI Performance/Design Requirements for the OCDMS Supervisory System.
3. Part I CPCEI performance/Design Requirements for OCDMS Support System.
4. Final Report OCDMS Hardware Design
5. Final Report OCDMS Software Design
6. Technical Advisement Memorandum: Logic and Signal Design
7. Technical Advisement Memorandum: Man-Machine Interfaces
8. Technical Advisement Memorandum: Preferred Computer Manufacturer Software
9. Management Level Briefing Report
10. Management Level Briefing Report
11. Computer Selection Preference Report

A. OCDMS System Discussion

1. System Goals

Primary system goals of the OCDMS are:

a. Provide assurance of the integrity and operational capability of AAP experiments.

b. Provide the capability to control the conduct of experiment operations and acquire and process experiment data.

c. Provide a vehicle for further development of on-board checkout, maintenance and data management techniques.

Each of these general requirements was reflected in specific requirements determined during the study period; these are discussed in following subsections. These requirements are derived from experience on ground checkout and data management systems, particularly the Saturn ground systems, and from requirements for a similar checkout and data management system in development for the Air Force MOL vehicle. Existing AAP documents and discussions with NASA personnel resulted in some refinement of requirements.

2. Nature of Experiments

In order to arrive at workloads and hardware quantitative estimates, an analysis was performed to define a mission experiment mix that created a demanding workload for the system. From this experiement mix, an estimate was made of the various parameters that would influence system design. These included numbers and types of measurements and stimuli, data rates and volume, memory capacity, and other computer characteristics.

3. Operational Concept

Exhibit 5 depicts that part of the life cycle of a particular AAP mission in which the OCDMS participates. Each of the activities identified in the figure is discussed below, with particular emphasis on the ways in which OCMDS could contribute to attaining the objectives of the activity. Details of execution and exact techniques to be employed cannot be determined at this time; many will depend on detail mission planning. This conceptual plan is presented here only as one that is plausible and demanding on the OCDMS--especially the software. From this concept of the operational utilization of OCDMS, the functional requirements which must be met by the OCDM software are derived. The completeness of the OCDMS roles described assures completeness of functional requirements with respect to currently anticipated OCDMS functions; expandability and flexibility for each function will be addressed, in context, in subsequent sections describing the software design.

4. Ground Operations

o Installation and Integration Operations

During these operations, the experimental apparatus is mechanically and functionally mated with the on-board structures and systems. Normally, tests are performed at successive points during installation to verify the compatibility of the interfacing elements prior to attempting to verify the functional integrity of the installed apparatus.

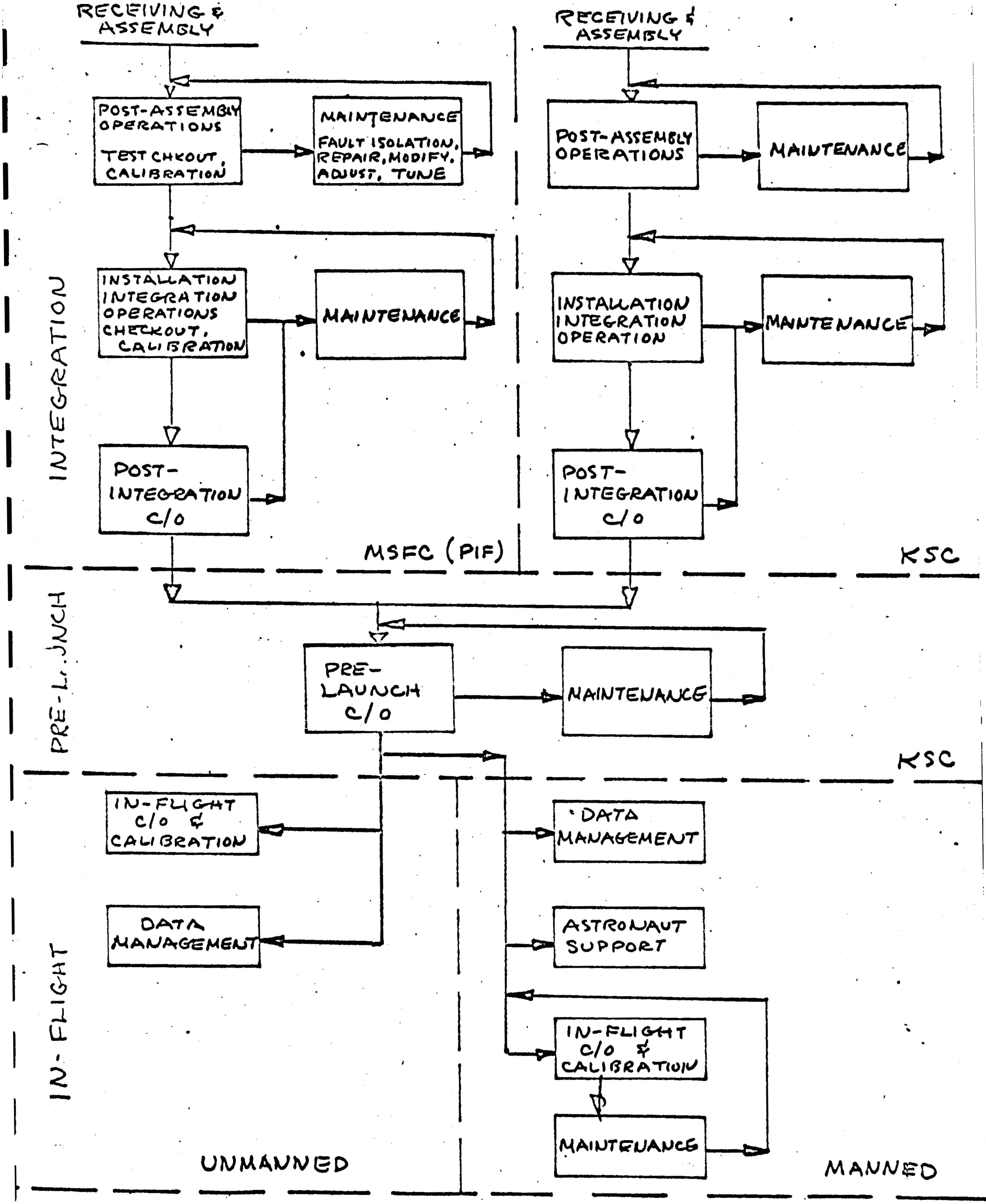

EXHIBIT 5- SAA MISSION PREPARATION AND EXECUTION ACTIVITIES INVOLVING OCDMS

During these operations, the flight OCDMS will be used, and the primary operational mode will be semi-automatic. The available test points will be limited to those accessible to the OCDMS signal adapters, plus those used in tuning and adjusting the apparatus. The operator thus is able to utilize more fully the automated procedures, selecting steps, blocks and sequences which suit his purpose. The extensive involvement of personnel in these operations dictates the ability to dwell on a test step, to automatically recycle a sequence of steps, and to suppress execution of selected steps within a designated operational sequence.

The primary interface with the ground system operator is the Raytheon Display Console directly connected to the RCA 110A heretofore used for S-IC checkout at MSFC. Using the keyboard associated with the console, the operator selects steps or sequences for execution, identifies responses to be monitored and displayed on his CRT, halts execution of sequences or monitoring, switches the OCDMS from automatic to semi-automatic, etc.

During these operations more than a single experiment will normally be being installed at the same time. If the system could handle only a single experiment at a time, a certain amount of queuing would result in time lost while waiting on the system. It thus becomes highly desirable that the ground system/OCDMS complex be able to independently service as many experiments as there are display consoles (including the on-board astronaut's console).As will be shown , this multi-servicing capability becomes a mandatory requirement for the OCDMS during in-flight operations.

It is expected that, for certain flights and for certain experiments, installation and integration will be done as KSC. In such instances, once installed and checked out (using needed special support equipment) the flight OCDMS is operable as a "free" system, independently of a ground system, via the on-board display and control console. Use of this capability limits activities, in that only limited multi-servicing of experiments is practical from a single console. However, since the requirement for such use at KSC is expected to be limited (i.e., most such operations are expected to be conducted at MSFC), this limitation is not considered significant. Alternately, an ACE system at KSC could be used to provide multiple console operator stations, if scheduled availability of ACE systems permitted. The point is, use of ACE is possible, but not mandatory, during any installation and integration at KSC.

- Post-Integration Checkout

The objective of post-integration checkout is to verify the functional and operations integrity of the on-board complex comprised of the individual experiments, OCDMS, and the other on-board systems which support the experiments. A series of overall and individual testing operations are normally conducted. It is important to note that the OCDMS is required to support the testing activities, by serving to interface the on-board complex with the testing personnel, via the ground system.

In the conduct of these tests, the operators will utilize their consoles (both on-board and ground) in two different ways:

a) To simulate expected in-flight demands to be placed upon the on-board complex by astronauts and/or ground-based personnel, and

b) To monitor and modify the actions performed by the on-board complex in response to these operational demands, in order to verify that the responses are proper.

These categories of use define two distinct levels of communication which must be maintained, each of which imposes its own requirements upon the OCDMS. For example, it is to be expected that, on occasion, a ground system operator will want to monitor an on-board function which would not normally be sent over PCM during actual flight operations. Thus, it must be possible for the OCDMS to sample, process, and the transmit values of such functions without interferring with the normal execution of the programmed experiment operation requests without adversely affecting the "normal" operations being conducted.

At MSFC, these operations will be conducted using the former S-IC checkout system as the ground system. When done at KSC, a similar capability is available using ACE as the ground system. Alternately, a capability exists for using the OCDMS alone, with operations being controlled from the on-board display and control console.

- Pre-Launch Checkout

These operations will be conducted at KSC, and consist of two types of activities:

a) Further post-integration checkout, calibration and functional verification conducted in conjunction with the spacecraft and vehicle assembly opertions at KSC.

b) Flight-readiness testing performed immediately prior to launch.

- Vehicle Integration Operations

For those experiments installed in the LEM, these testing operations are conducted at the Spacecraft Integration Facility at KSC. The ground system utilized is one of the ACE systems installed at that facility. For those experiments installed in the Instrument Unit or the S-IVB, it is envisioned that a free-standing, ground-based OCDMS (part of a LEM substitute) would be used in the VAB, prior to the mating of the spacecraft to the launch vehicle. This free-standing OCDMS is required since the flight OCDMS is mounted in the LEM and the distance between the VAB and the SIF precludes its use prior to the mounting of the spacecraft on the vehicle. The free-standing OCDMS would connect into the vehicle-mounted signal adapters in the same way that the flight OCDMS will after the spacecraft is mounted. Thus, the software to be used by the flihgt OCDMS can be both validated and utilized prior to the physical availability of the flight OCDMS.

The activities performed during these operations, at either facility, are similar to those discussed under Post-Integration Checkout, above, and impose similar requirements on the OCDMS

- <u>Flight Readiness Testing</u>

Experiment testing during the countdown is not expected to be extensive. This follows from the expectation that few of the experiments will be operational during launch: Most will be quiesent until the vehicle is "on station." Since the operability of the experimental apparatus, and the associated on-board system (including OCDMS), will have been established during post-integration checkout, the primary requirement for flight readiness testing is the determination that nothing has occurred which affects operability. If an active checkout is planned for this period, it would have many of the qualities of the post-integration checkout. On the other hand, a limited check of system integrity and continuity could be planned. In either case, the system requirements for the software are consistent with those previously determined for such check-out operations. Control would clearly reside with the OCDMS even in this last pre-launch operation.

- <u>Ground Maintenance</u>

Ground Maintenance is defined to be those activities resulting from the determination, during other ground operations, that part or all of the on-board complex is not functioning properly. Included are: fault isolation, fault correction (repair, adjusting, tuning, modifying), and calibration. The OCDMS is both a potential subject of, and a tool for, the performance of maintenance.

The collection of experiments, and the configuration of the associated on-board experiment support systems will vary greatly from one vehicle to the next. As a result, personnel charged with performing maintenance will have little opportunity to become thoroughly familiar with the details and characteristics of this equipment. (This is in sharp contrast to the situation regarding the relatively unchanging vehicle and spacecraft). It thus is necessary that maintenance operations be simplified, from a personnel standpoint, in order to improve overall maintainability. Much of this simplification can result from the effective use of OCDMS as a Maintenance Tool. Known maintenance procedures can be stored in memory and presented by the OCDMS. Additionally, the OCDMS should provide for flexible, possibly adaptively planned, test procedures.

- Fault Isolation

  The OCDMS self-test mode of operation provides extensive capabilities for isolating, to the replaceable or redundantly maintained module, faults occurring within the OCDMS. To the maximum practical extent, the automated procedures for each experiment should include fault isolation procedures appropriate to the experiment. The OCDMS must be capable of handling the two approaches to fault isolation, an arbitrary mix of which may be appropriate for a given experiment:

a) Sequential testing, in which successive tests further isolate the fault to more narrowly bounded parts of the equipment under test; the next action to be taken from a test step may be either manually or automatically selected;

b) Failure analysis, in which responses corresponding to an appropriate sequential set of stimuli are analyzed, and the location of the failure deduced from a knowledge of the possible failure modes; the selection of tests and the analysis can be manual, automatic or a combination thereof.

Regardless of the mix of approaches used in a particular instance, fault isolation is an "unusual" activity which imposes additional requirements on the OCDMS. For maximum utility, the OCDMS should perform fault isolation, on a "non-interference" basis, concurrently with the execution of other un-affected automate procedure.

o <u>Fault Corrections</u>

The relationship of fault correction activities to OCDMS is dependent upon where the fault occurred.

o <u>OCDMS Hardware Fault Correction</u>

Operational use of OCDMS is suspended during OCDMS self-check, and would normally not resume until after the fault had been corrected by replacement of the module identified as faulty or a degraded mode of operation determined. Depending on the type of failure, the interrupted operations would normally be re-started. Some modification of the OCDMS software would follow module replacement in some instances, such as a networks change or a change in the calibration curve of an A/D Converter. The software must also provide the flexibility of function control to modify, on-line, the OCDMS procedures to best utilize whatever equipment configuration remains after an uncorrectable failure.

- <u>OCDMS Software Fault Correction</u>

The nature of the faulty software module, and the extent to which it enters into OCDMS operations, will determine the extent to which the OCDMS can continue to be used during "repairs." The OCDMS should possess the capability for the direct entry of a "quick fix" where such is possible. Permanent repair should be affected as an off-line activity, and should always be handled as a change since the associated software documentation is always affected to some degree.

- <u>Experimental Apparatus Fault Corection</u>

The extent ot which these faults can be isolated is largely a matter of choice on the part of those who design the experiment and the procedures associated therewith. To the extent that the repair re-routes or changes the characteristics of an OCDM/Experiment Signal Channel, both the hardware and software of OCDMS may require compensating modifications.

o Calibration

Two kinds of calibration activities are identified as follows:

a) The adjustment or tuning of hardware in order to force a signal or response to conform to a predetermined standard, and

b) The measuring of the deviation of a signal or response from a pre-determined standard, in order that a corresponding correction, to remove the effect of the deviation, can be applied to the sampled data during processing.

Both kinds occur during maintenance operations, both for the OCDMS and for experiments. Each requires the existence of certain operational characteistics in the OCDMS, as discuesed below.

o Adjustment/Tuning

During adjustment and tuning of experimental appratus, it is necessary for the operator to select the stimuli to be applied and the responses to be measured, and to cause the OCDMS to either "dwell" or continuously recycle until the desired response value is reached.

o Measurement/Correction

The more dependable approach to calibration is based upon the short-term repeatability of experimental apparatus responses. In this approach, a programmed calibration procedure is executed which applies a succession of pre-determined stimuli, compares the response obtained to a pre-defined standard, and uses the resultant error terms to derive a calibration correction function. In practice, the correction function coefficients are transformed so that calibration correction and conversion to engineering units is done simultaneously. Using this approach to calibration, the calibration procedure for a given experiment can be automatically executed prior to, and periodically during, the operation of the experimental apparatus; the procedure can also be called-up at any time by the operator. To the extent that this technique is used in the experiment primary data points, an increased assurance of data validity should be acquired.

Where this approach is followed, it is expected that the OCDMS will perform all of the operations necessary for the conversion of sampled raw data into corrected measurement values in engineering units. To accomplish this, a calibration procedure is required for each signal channel to be sampled, along with an algorithm for determing when to execute the procedure and a means for processing the calibration data into parameters to be applied to each operational sample from that signal channel.

5. <u>In-Flight Operations</u>

- <u>Un-Manned Missions</u>

For un-manned missions, the ground system used to control and monitor OCDMS operations is GOSS. The ground-to-vehicle bit rate for the command link is 1 kc. In addition, the communications network which ties the IMCC operator to the vehicle is a store-and-forward type, and the legs of the net have widely varying bit-rate capacities. These considerations, plus the transmission delays and/or noise resulting from range and line-of-sight problems, imply time lags, in operator-to-vehicle commands, which could vary widely and range up to minutes. Because of the variability and possible magnitudes of these command/response lag times, it is required that OCDMS be virtually an autonomous system and that control commands from the ground be transmitted largely on an exception basis. To the maximum possible extent, the sequences of operations to be performed during the entire mission should be pre-programmed into OCDMS.

o <u>Checkout and Calibration</u>

These operations normally will be conducted as elements of the operating procedure for the various experiments, usually as a part of the apparatus turn-on procedure and periodically (in some cases) during the operating cycle. Independent initiation from the ground would be done only when felt necessary to verify or supplement the automatic operations. If the results of the checkout indicate a fault, the ground operator may be called upon to determine which of the following should be done:

a) Ignore the fault, operate the experiment, and attempt to compensate for the fault by subsequently modifying the data.

b) Switch to an alternate mode of operation of the experimental apparatus.

c) Terminate the experiment associated with the fault (i.e., suppress subsequent execution of the programmed operating procedures for that experiment).

The programmed procedure should always effect one of the above alternatives, with the action of the ground being to override that pre-selected choice, when desired.

o <u>Data Management</u>

The data management role of the OCDMS is conceived to include both the control of the experiments, and the processing and control of the data stream from the active experiments to the PCM transmitter. Control of the experiments involve turn-on, checkout, calibration, operational mode switching, and turn-off activities, plus the scheduling operations associated with determining when these activities are to be initiated. Data control involves periodic data sampling, data correction, filtering, conversion to engineering units, editing, formatting and transmitting, as determined by the current activity of the experiment and the requests of personnel.

o <u>Experiment Scheduling</u>

The OCDMS will contain a pre-programmed scheduling procedure for each of the experiments, to determine when and under what conditions the experimental apparatus should be operating. Ground control should be able to modify these scheduling procedures when necessary.

Whenever the experiment is quiescent, the procedure which defines the turn-on conditions will be periodically executed. When the conditions are met, a pre-programmed sequence of procedures is executed (turn-on, checkout, calibrate, operatoe, etc.).

Whenever the experiment is operating, the procedure which defines the turn-off conditions similarly will be periodically executed. When the turn-off conditions are met, a corresponding sequence of shut-down procedures is executed.

- <u>Experiment Start-Up</u>

  The start-up of an experiment will be triggered either by the scheduling procedure or by a ground command, and will normally invovle the execution of a succession of procedures for turn-on, checkout and calibration. The data acquired as a result of procedure execution must be processed, identified, and formatted for transmission to the ground via PCM.

- <u>Experiment Operation</u>

  The experiment operating procedure will consist of a specification of the control operations to be performed, of the experiment output signals to be sampled and the sample rates required. Experiment operation will normally consist of periodically sampling experimental data values, correcting and converting the samples to engineering units, processing the samples (editing, compressing, filtering, correlating, etc.), and formatting the processed data for ground transmission.

Where an experiment has more than one operational mode, a transition procedure will be periodically executed to determine if the conditions have been met for a change of mode. The transmition procedure will also define the actions required of the OCDMS to effect the transition to the new mode.

Because of the range of potential experiments--from biological condition monitoring to active observation and measurement--the duty cycle, activation cycle, number of data channels, and the samples rates for the experiments will vary over very wide ranges, as will the extent to which the experimental procedures can be automated. Also, the OCDMS must respond to some experiment results with modified procedures. This range of variation imposes upon the OCDMS software a strigent requirement for versatility and adaptability.

b. Manned Missions

For manned missions,OCDMS-related operations will strongly resemble those conducted during post-integration checkout. Direct ground control via the command link is expected to be minimal. The flight crew must be able to exert and converting the samples to engineering units, processing the samples (editing, compressing, filtering, correlating, etc.), and formatting the processed data for ground transmission.

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b. Manned Missions

For manned missions,OCDMS-related operations will strongly resemble those conducted during post-integration checkout. Direct ground control via the command link is expected to be minimal. The flight crew must be able to exert primary control over the OCDMS during normal operations, such that exercise of ground control over the OCDMS during normal operations, such that exercise of ground control is by permission only. Conversely, the ground must be able to acquire primary control during special situations. Periodic reactivation of a timer switch by the crew provides this capability if the crew has control whenever the switch has been recently activated, and the ground has control otherwise. Under normal conditions, ground control is expected to be exercised via the flight personnel through the use of voice channels. Where direct ground control is exercised, operations will conform to the pattern for un-manned missions, as described in the previously

- Checkout and Calibration

These operations will normally be initiated automatically as a part of the pre-programmed start-up procedure for each of the experiments. In addition, the presence of flight personnel implies that these operations will also be selectively initiated via the on-board display and control console.

Post-launch changes in possible experiment conditions, could create the need for careful re-examination of the experiment equipment to ascertain its capabilities in the new, unanticipated conditions. The software must provide capability for conducting such unanticipated tests--assuming the data points are available.

- Maintenance

The hardware configuration of the OCDMS is such as to permit replacement by redundancy and/or adjustment of modules found to be faulty. The self-test mode serves as a maintenance aid to permit rapid isolation of the faults to a module, and also permits assessment of the capability for degraded mode operation. For some experiments, it is expected that fault isolation procedures would provide the basis for determining optimal degraded mode capabilities in the event of a failure in the apparatus.

The extent to which on-board maintenance can be achieved is subject to question. The importance of such a capability relative to future long-duration missions dictates the need for answering that question. The implications on the software system to provide the capability is the same pre-planned and adaptive procedures discussed previously.

- Data Management

These operations will be essentially the same as previously described for un-manned missions except that on-board control can be exercised to initiate, modify, repeat or delete all or part of each experiment.

In addition, the wider-ranging mission flight profiles projected for the manned missions adds emphasis to the requirement for OCDMS to be able to buffer large amounts of sampled experimental data over periods when the spacecraft is not in range of a ground station. The capability to subsequently interleave the buffered data with current data, and to maintain the integrity of both, requires that both data labeling and data compression be affected prior to PCM transmission. Data compression techniques available to OCDMS include digital filtering, rate sampling, band limiting, orthogonal polynomial characterization, cross correlations, autocorrelation, etc. The parallel nature of the data streams and the operationally serial nature of OCDMS restricts the extent of such computation which can be done in real-time.

o <u>Astronaut Support</u>

Averaged over a mission, these operations are not expected to significantly load OCDMS. However, over the short term, peak loadings may be induced which saturate the capacity of OCDMS. To minimize such problems, these support operations must be considered to be of lower priority than the execution of scheduled procedures, unless a higher priority is explicitly requested.

The on-board display and control console would be used to request, control, and receive the results from these operations, as appropriate. In addition to the checkout and maintenance operations previously discussed, the kinds of actions which can be taken include the following:

a) Entry, for subsequent PCM transmission, of observational data from experiments which are not instrumented for automatic data acquisition (i.e, biological experiments, etc.).

b) Requests for the monitoring of experimental data (to assess equipment performance, for correlation with visual data, etc.).

c) On-line performance of mathematical computations (related to the analysis of experimental data, assessment of equipment performance, filtering or analysis of observational data, etc.).

To effect the astronaut support, the software must provdie the following:

a) Alphanumeric input to memory, e.g., to accept, store and later transmit astronaut entered data and observations.

b) On-line function determination using readily called-for software, i.e., capability for the design of a sequence of numerical or control operators using function-named inputs.

6. Hardware System

A configuration of equipment suggested for meeting the above objectives is shown in gross block diagram form in Exhibit 6. The system, the rationale and design of which will be developed subsequently, comprises five basic elements:

(1) A computer

(2) Auxiliary memory in the form of two magnetic tape units

(3) A computer interface unit (CIU) through which

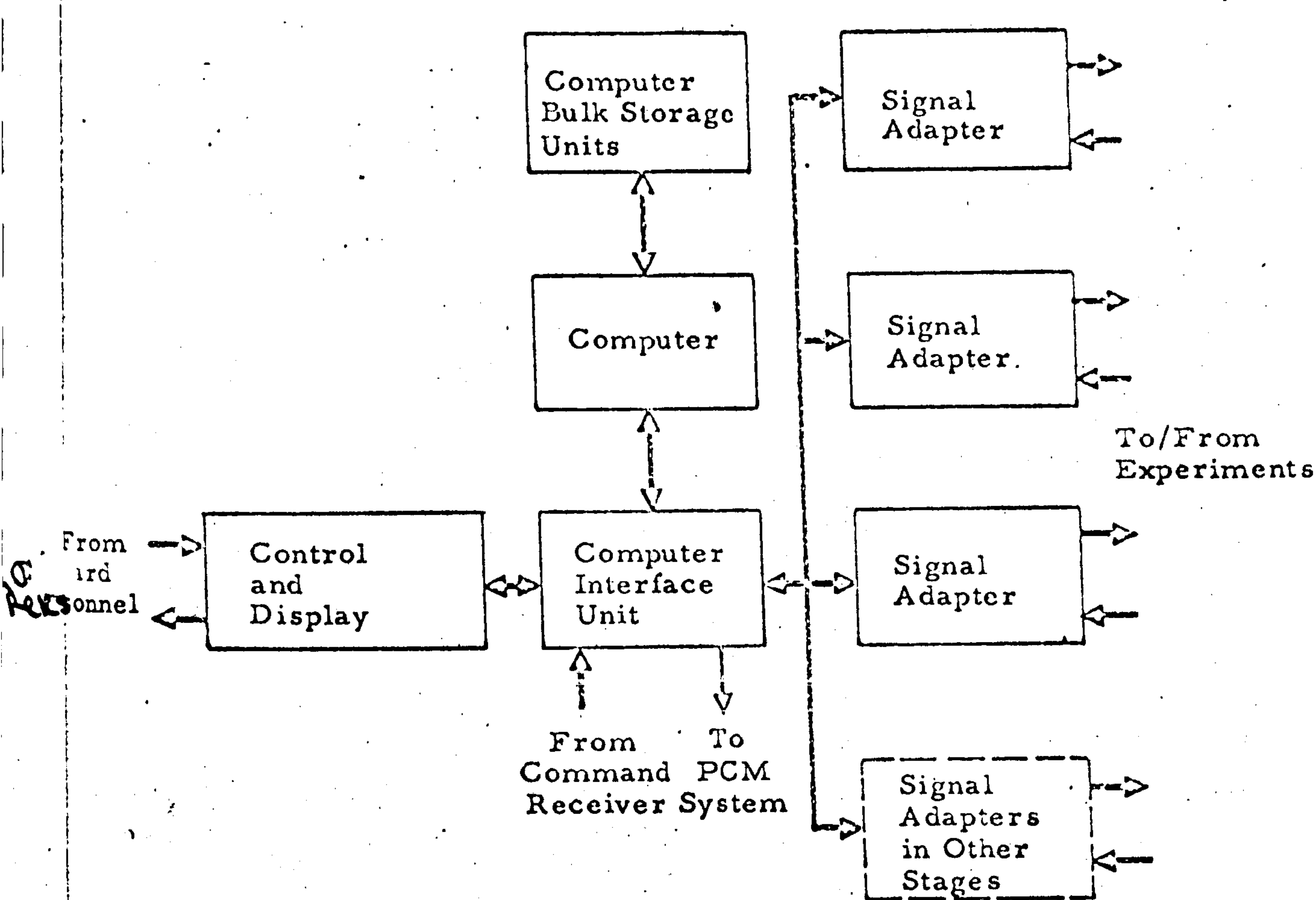


EXHIBIT 6- OCDMS SYSTEM BLOCK DIAGRAM

the computer communicates with the rest of the system and the outside world

(4) A control and display unit (CDU) for system communication with the crew

(5) One or more (probably three) signal adaptors comprising stimulus, measurement, and switching equipment, which act as buffers between the OCDMS and the experiments.

In addition to these units, the normal LEM PCM telemetry and uplink command system are required for communication with ground sites.

The system is commanded to perform its various tasks through either the CDU or the uplink command system. The software (described in the companion report) is designed in such a manner that the system operation does not change, regardless of the source that supplies commands.

The OCDMS performs its checkout and data management tasks by commanding stimuli and control signals to be applied to the experiments through the signal adapter, and by requesting sampled measurements of experimental parameters through the same signal adapter. The sequence of these operations is determined by computer programs prepared to effect pre-determined operational and checkout procedures, or by realtime operations of the space crew or ground crew.

Simultaneously, or as commanded by the crew or ground controller, the computer records the results of its operations on tape and/or displays them to the crew. Also, results can be sent to the ground via telemetry, either in real-time or as a playback from recorded tape.

7. Software System

In accordance with the on-board checkout and data management operating concepts defined by NASA, the gross performance characteristics and design criteria for the software system must provide for the following:

a) Experiment checkout, control and data management functions are to be fully implemented by the OCDMS equipment and procedures for each AAP mission.

b) Semi-autonomous operations at various sites are to maintain the integrity of the hardware systems and software interfaces, and provide continuity to experiment information flow.

c) An open-ended and modular organization of programmed procedures and data records is to provide convenient additions or deletions as necessary, to satisfy any particular phase of the experiment checkout or data management.

d) Astronaut/Test personnel commands initiated at the OCDMS Control and Display Console or communicated by the Uplink Digital Command System are to provide a dynamic control capability, including optional modes of operation and changes to Experiment/Checkout Procedures.

Following these operational goals, the functions to be performed and implemented by computer programming activities include those provisions which, in both checkout and data management tasks, will allow the following:

a) A method of achieving minimum obsolescence of equipment and experiment techniques between various AAP missions; to achieve this goal, suggested by cost considerations, the OCMDS computer is a general purpose machine and Signal Adaptor modules are plug-in. System control is primarily a software function. Thus, the system provides the necessary flexibility, adaptability and expandability to satisfy the succedding AAP mission requirements.

b) An approach that does not increase the quantity and complexity of ground checkout equipment for increased experiment integration work loads; since, any approach to even modify moderately the already developed ground systems to handle AAP experiment requirements would have significant impace on both cost and schedule.

c) Standardization of experiment checkout procedures, evaluation methods, and processing of test result data to achieve simplification of vehicle records, test records and experimental data; software performance/design requirements must impose the information processing constraints, and specify the method of data formatting and representation by which this is to be accomplished.

d) Traceability and correlation of experiment and test result data at all sites and for post-flight analysis; this means that data processing functions and data representation must be maintained common through various phases of the mission so that preserved historical records can be easily compared and evaluated.

e) Preparation of Experiment/Checkout procedures that are applicable for all phases of a mission; to minimize the cost of test planning, ease the configuration management burden and assure repeatability of test procedures, it is desirable that all test programs may be prepared by a unified planning effort and site-to-site changes in Experiment/Checkout procedures chiefly consist of additions or deletions of test steps, or programmed statements depending on the particular site responsibility.

f) Preparation of commond documentation for in-space and ground checkout operations; this is to reduce the quantity of test documentation and increase the effectiveness of test planning management. This can be accomplished with the OCDMS because documentation referring to the data base is the same, and on-board as well as site peculiar parameters are produced once with follow-on editing and updating accomplished as necessary.

- OCDMS Software Elements

The software associated with the OCDMS is divisable into three major categories :

Operating System Programs (OSP)

Experiment Procedure Programs (EPP)

Support System Programs (SSP)

Associated with each of these categories are the data bases which, with the programs, comprise the OCDMS software. The OCDMS systems software is defined to consist of the Operating System Software and the Support System Software.

A primary functional distinction among the categories is that the OSP and EPP are executed on-line (i.e., during normal operational use of the OCDMS) and the SSP is executed off-line. Due to the many problems which can be encountered by an on-line, real-time system such as OCDMS, a definite software design objective is to relegate all possible computing tasks to the off-line system. In this way, the impace of complex timing relationships, physical environment interactions, communication difficulties, and conflicting demands can be minimized. The on-line system is simply relieved of as much work as possible in order to more nearly optimize performance in this environment.

A similar design objective applies to the division of tasks between the OSP and the EPP: functional elements not unique to a particular experiment procedure should, to the maximum possible extent, be parametrically defined and incorporated in the OSP. To the extent done, the ECP then consists of data which identifies the OSP functions to be performed and the experiment-peculiar parameter values which particularize the functions. This is consistent with the objective for software generality and the functionsl requirement for concurrent activitites.

- Operating System Programs

Functions and Requirements

The operating system must include those functional elements which are, or can be made to be, independent of particular experiments or experiment procedures. Thus, the operating system must manage the intra-and inter-OCDMS flow of information, both data and control, to fulfill the demands and constraints imposed by the experiment procedures, the operators, the experimental apparatus and the OCDMS elements. To fulfill this role, it si necessary that the design of the Operating System provide a structural and functional organization capable of effectively and efficently performing the following activities:

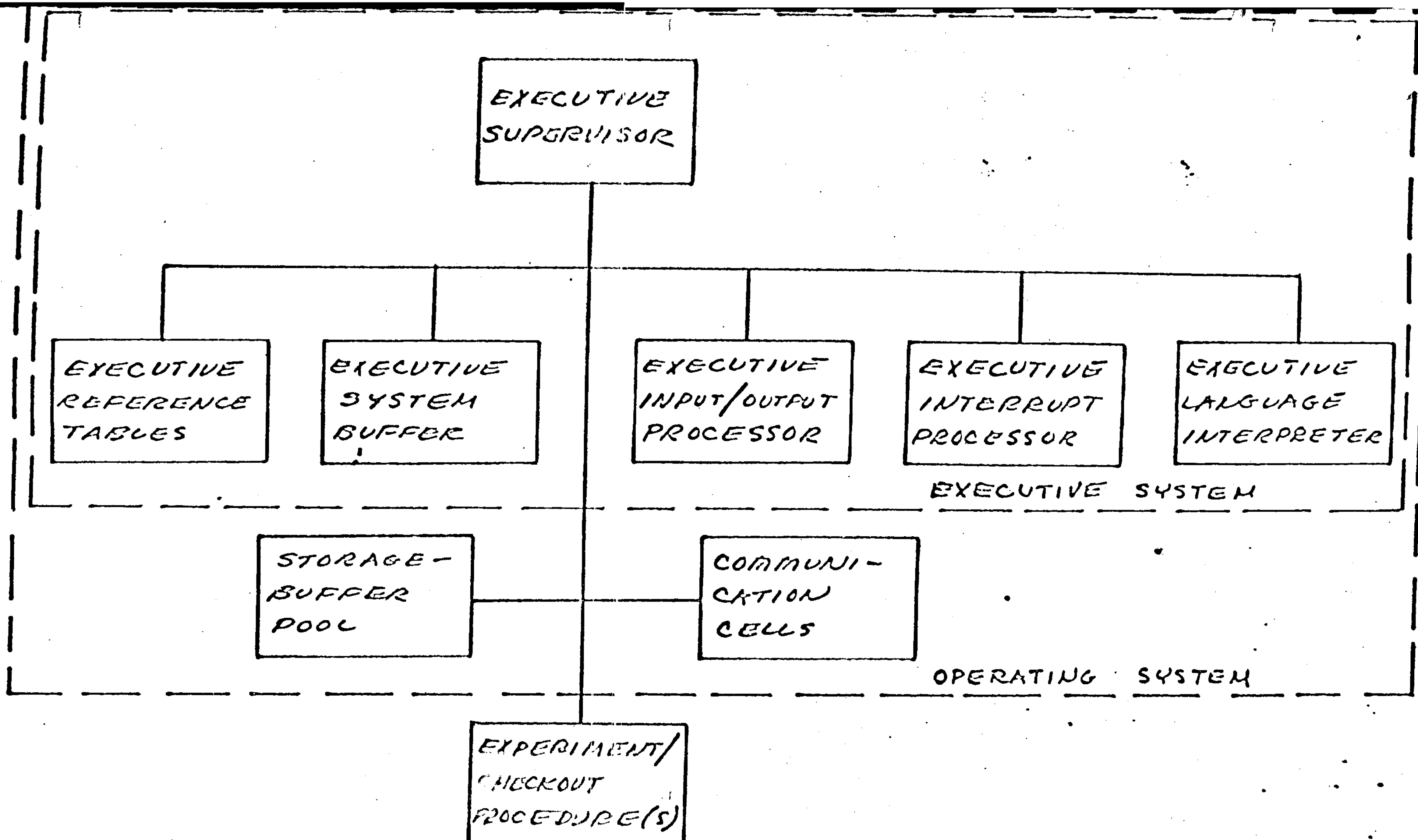
1) Handling of system input and output;
2) Queuing of measages and data;
3) Scheduling of system tasks;
4) Assessing of priorities between procedures and associated tasks;
5) Performing housekeeping functions for programmed procedures;
6) Responding to and processing interrupts;
7) Detecting, recognizing and dealing with error and emergency conditions;
8) Coordinating of system functions under varying loads;
9) Allocating of storage space in memory.

- Operating System Structural Description

Structurally, the OCDMS Operating System will consist of three major parts: The Executive System, Communication Cells, and Storage-Buffer Pool. In order to maintain the strict, continuous control necessitated by its operations control functions, at least a portion of the Operating System would be required to reside in core at all times during operational use of the OCDMS. This portion will be referred to as the Resident Executive and would consist of portions of each of the three major parts of the Operating System. The contents and respective sizes of each of the three major parts are enumerated below. Exhibit 7 illustrates the elements of the OCDMS on-line software system.

- Executive System

The Executive System is that part of the OCDMS Operating System which would mechanize the man-machine interfaces required for on-line decision making and control, together with the interfaces between the Experiment Procedure Programs and the remainder of the OCDMS (including both the experiments and operations personnel). It is responsible for providing the OCDMS software system with the mechanics for interrogating external devices, evaluating responses, controlling internal procedures, and performing utility functions on request. To this end, the Executive System will consist of the following:



OCDMS ON-LINE SOFTWARE SYSTEM ELEMENTS

EXHIBIT 7

1. Executive Supervisor: a set of executable routines whose purpose is to initialize, initiate, monitor, and coordinate the various activities of the overall software system. This necessitates it having the capability of performing the following tasks:

(a) Loading and initializing the system;

(b) Generating necessary control and communication linkage between system elements;

(c) Scheduling tasks for the system;

(d) Interrupt control;

(e) Providing for automatic error and fault detection, recognition, and appropriate reaction;

(f) Handling overload in case system is temporarily overwhelmed by demands for data manipulation and processing tasks;

(g) On-line modification of procedures and parameters by the Astronaut/Test Personne;

(h) Function monitoring, limit-checking, conversion to engineering units.

2. Executive Reference Tables: a set of tables containing information required by the other elements of the operating system (particularly the Executive System) in their execution. This would include profiles reflecting the status of the experiments, the OCDMS signal adapters, and the other OCDMS hardware; the Precedence List, which contains the current

schedule of procedures to be executed; the loader symbol table (core map); priority queues and aciton preference lists constructed by the Executive Supervisor; tables containing certain data and code conversion constants; etc.

3. Executive System Buffer: an area of computer memory reserved for the temporary storage of executable routines which, because of frequency-of-use, are resident in memory only when required. These would include Executive Options, Exception Routines, Service/Support Routines, and Utility Routines called into core from the Subroutine Library in bulk storage by the loader routine, a part of the Executive Supervisor.

4. Input/Output Processor: a set of formatting routines, linkage variables indicating applicable buffer areas or data storage -ocations, and the actual input/output channel and device control routines. The I/O Processor will also contain those routines responsible for the dynamic allocation of data storage areas.

5. Language Interpreter: a set of routines by means of which commands entered on-line by operations personnel are translated into the spcific OCDMS actions required to implement the commands. This set also includes the collection of subroutines which mechanize the actions required to execute the Experiment Procedure Programs or other applications programs written in the OCDMS symbolic language.

6. Interrupt Processor: a set of executable routines (Interrupt Service Routines) and linkage mechanisms to be used for completing the identification of interrupt signals, if necessary, and subsequently servicing the indicated interupt conditions. To reduce the interactions and queuing associated with the dyanmics of a real-time system such as OCDMS, only essential operations are done by the Interrupt Processor; where possible operations associated with interrupts are passed-over to the Executive Supervisor for scheduling and execution.

- Communication Cells

There would be a need for two types of communication cells; Procedure Block Files (PBF) and Unit Control Blocks (UCB). These contain information required for the interpretation and execution of Experiment Procedures, and for the control of the Signal-Adapter/Experiment interface. The two types are briefly described below:

a) PBF: a set of parameters associated with the current set of Experiment Procedures, in the form of either literal data or "pointers" to where the data is located. These parameters include coefficients for conversion of data samples to engineering units, measurements limits, switch-timing relationships, etc.

(b) UCB: a set of parameters pertaining to the stimulus/response requirements, and status, of a particular unit or class of signal adapter, experimental apparatus, or other hardware contained in or interfacing with OCDMS. These parameters include function-name-to-control-code conversion tables, calibration coefficients, etc.

- Storage-Buffer Pool

The Storage-Buffer Pool is that set of computer memory which would be reserved for the storage of data which is "in transit" through the system (input data, intermediate results of processing, formatted data ready for output, etc.). The Storage Buffer Pool would be divided into buffer units of a size appropriate to the range of sizes anticipated for the sets of data to be stored. These buffer units would be dynamically allocated for data storage on an as-needed basis by routines contained in the I/O Processor. Data stored in allocated buffer units would include arrays of data received through external devices (e.g., Command Receiver/Decoder, OCDMS Control/Display Console, and Signal Adapter); the results of exercises performed internal to the computer (e.g., arrays of converted or reformatted data); and arrays of processed and formatted data awaiting output to external devices such as those noted above. Allocated buffer units no longer required for data would be returned to the Storage Buffer Pool and would be available for re-allocation.

- Operating System Functional Description

In rendering a functional description of the Operating System, it will be convenient to consider the many particular functions required of it in terms of the eight general areas listed below. This grouping is only a convenience of communication and does not imply any type of corresponding structural organization. Reference Exhibit 8, for an illustration of the functional inter-relationships of the various structural elements of the on-line software system.

1. Inter-program communication;
2. Resident system loading and initialization;
3. Non-resident system management;
4. Scheduling;
5. Interrupt control and servicing;
6. Input/Output processing;
7. Function monitoring;
8. On-Line operations control.

o Experiment Procedure Programs

Size and Number

The total number of Experiment Procedure Programs for any given AAP mission will be a function of both the number and the complexity of the experiments associated with the mission; the average size of a procedure will be a function of the complexity. The average number of procedure programs per experiment was estimated to be 10. A typical set-of-ten might include the following:

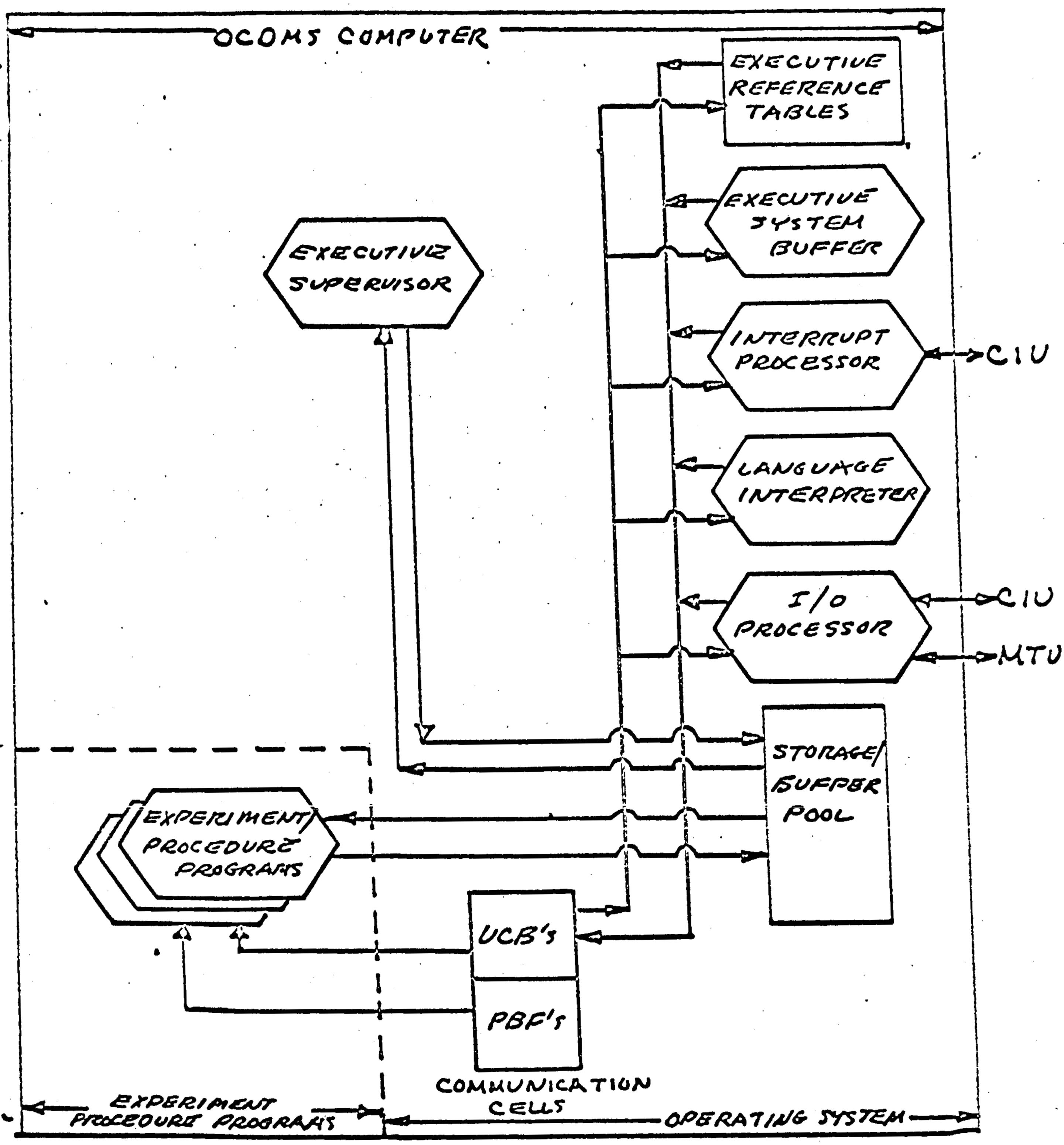


EXHIBIT 8- OCDMS FUNCTIONAL RELATIONSHIPS OF SOFTWARE SYSTEM ELEMENTS...

Turn-On Scheduler; Turn-On Procedure; Alignment Checkout; Simulated Operation Checkout; Pre-Operation Checkout; Calibration; Operational Mode 1; Operational Mode 2; Turn-Off Procedure; Fault Isolation Procedure. Based on experience with the DAC S-IVB system and with the LCCC/MLC/ATOLL II design, both of which structured procedures in the manner contemplated for OCDMS, procedures may be expected to range from 100 words (or less) to over 2,000 words, and to average le less than 500 words.

Applying these estimates, it is found that the estimated average total procedure size per experiment is 5,000 words. Over the 10 to 60 range of experiments per mission, the total number of procedures ranges from 50,000 to 300,000 words.

- Support System Requirements

Identification and Definition of the OCDMS Operating System and overall software requirements determine to a considerable degree the Support System requirements. All possible computing tasks should be processed by the off-line system in system in order to relieve the on-line operation of time consuming and complex activities. The Support System serves to automate the preparation, validation and maintenance of the programs and parametric data required for operation of the on-line OCDMS; it includes both software and the computer hardware required for the execution of the software. The value of the OCDMS Support System lies in the following areas, all of which are attainable design objectives:

1. Improved Management Control of software preparation and use.
2. More effective Configuration Management.
3. Inhanced Quality Control and Reliability Assurance.
4. More effective utilization of limited manpower and computer resources.
5. Inhanced availability of adequate documentation.
6. Better Operations Planning and Control.
7. Greatly improved Engineer/OCDMS Communications.
8. A more efficient, versatile, effective OCDMS of greater utility and increased resistance to obsolesence.

- Manufacturer Supplied Software

One of the more significant factors influencing both attainable schedules and overall costs of the OCDMS project is the availability and useability of manufacturer supplied software. Final selection of the computer must be based on the evaluation of both the hardware and the adequacy of the associated software. Cost effectiveness is measured in terms of minimum schedule delays, high program production rates, and maximum computer utilization, all of which are related directly to the performance/design capability and the quality of documentation for this software.

The software in question is highly machine-dependent and can be classified as general-purpose. The programs and routines that fit this category include the following:

Assembly Program

Loader Program

Simulation Programs

Diagnostic Routines

Computer Utility Programs

Mathematical Subroutines

The manufacturer-supplied software will be a functional part of the OCDMS Support System. However, it is separately treated because it will be computer-oriented rather than OCDMS-oriented. The remainder of the Support System software will be more closely aligned with the specific characteristics and operational objectives of the OCMDS.

Preliminary review of the software available with the computers being considered for OCDMS indicates that the essential programs exist for each. Further analysis is required during subsequent specification preparation to evaluate each computer program component for compatibility with other Support System and Operating System functional elements.

- OCDMS Support System Software

Exhibit 9 depicts a Support System Software overall structure consistent with previous discussions, exclusive of that associated with software checkout and validation. The functional representation, at the level of detail shown, is considered to be machine-independent (although actual implementation will be highly dependent, both on the OCDMS computer selected and on the computer-- if different-- used for support

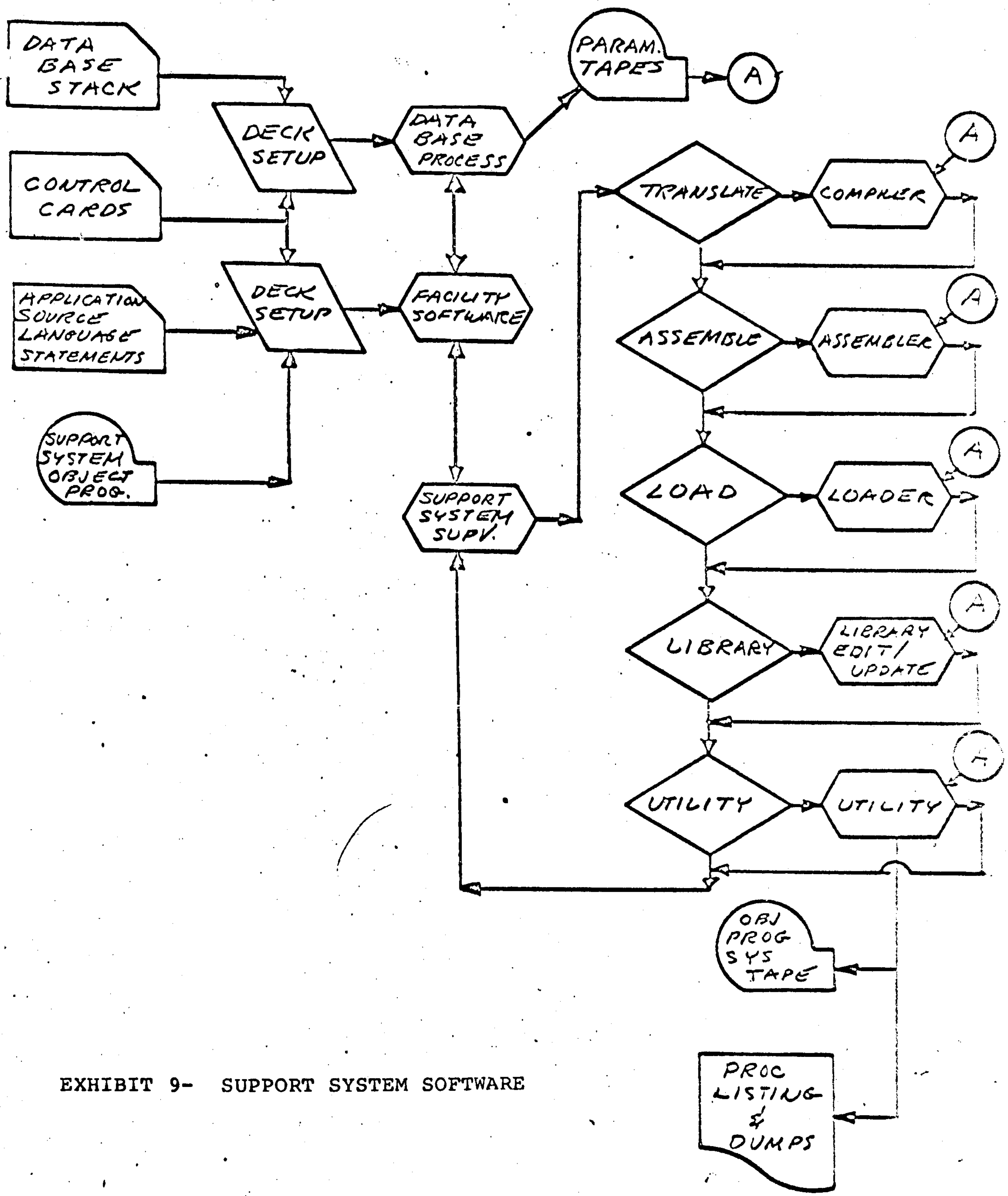


EXHIBIT 9- SUPPORT SYSTEM SOFTWARE

operations). The purpose, here, is to describe functional and design requirements independently of the particular off-line machine to be utilized. The OCDMS computer, with added peripheral equipment, or any other generally comparable computer would, from a technical standpoint, be acceptable for support operations.

III. Discussion of Problem Areas

The study described in the preceeding section performed under Contract No. NAS8-20367 has provided considerable "baseline" information. A great deal has been learned in its execution but, as is usually the case in studies of this type, the next generation of problems requiring resolution have also been defined.

As has been discussed previously, Onboard Checkout and Data Management Systems cannot truly be designed on the basis of "general" information.

Future work should be performed with the OCDMS system studied in context with a complete vehicle system including all its support equipment. The OCDMS System, The Candidate Vehicle System, and all its supporting equipment should be studied in context with all systems operations starting from post-manufacturing checkout and ending at conclusion of flight operations.

The next phase of OCDMS Systems Development must be implemented in such a manner as to permit study of the following:

1. Overall systems effectiveness of the Onboard Checkout and Data Management System by comparison to other methods and techniques.
2. A multiplicity of vehicle and ground systems concepts and configurations. This study should include determination of the optimum approach for the specific system.

3. All checkout operations requirements for OCDMS supported vehicle systems.
4. Effectiveness of various hardware and software methods of approach to this specific problem.
5. OCDMS Systems utilization and varification.
6. Self test and system fault isolation for this specific vehicle system supported by OCDMS and the specific OCDMS system.
7. Detail test operations step sequencing and synchronization between OCDMS and ground systems.
8. Safety condierations.
9. Support equipment requirements and trade-offs.
10. Determination of system and program costing characteristic.
11. Establishment of interfacing criteria with the On-Board Checkout Systems, Vehicle Sub-systems, Experimental Subsystems, and ground support equipment.
12. Establishment of MTBF and Reliability Data for OCDMS systems in order to establish Reliability requirements for the specific system.
13. Establishment of Quality requirements for OCDMS peculiar hardware.

14. Data Management and Data Compression techniques experimental evaluation

Data Compression Techniques are considered to include:

a) Data transformation

b) Parameter extraction

c) Selective monotoring

d) Predictor processing

e) Interpolators

f) Adaptive sampling

g) etc.

15. Evaluation of the capabilities requirements of the man/system interface, evaluation of various design approaches to the man/system interface, and experimental evaluation of the adequacy of these approaches.

16. The applications of multi-processing in OCDMS computer systems.

17. Overall availability, and maintainability studies in OCDMS systems.

18. Majestical considerations in the operation and maintenance of OCDMS systems.

19. Establishment of training requirements for personnel engaged in maintenance and operation of OCDMS systems.

IV Conclusions

The reasons for having OCDMS capability and the factors which determine the effectiveness of its implementation are not as obvious as the reasons for having any other basic vehicle subsystem.

The reason for having OCDMS incorporated in any vehicle system is to be found in the improvement to be realized in the effectiveness of subassesmbly checkout, subsystem checkout, and overall system test and checkout operations prior to launch and in the improvement in the effectiveness of operational concepts implicit in OCDMS are unique in that this is the first occasion wherein a vehicle subsystem is proposed to have significant applicability to operations commencing immediately after manufacturing.

In the past, vehicle systems design envolved along disciplinary lines. The overall vehicle system was divided in terms of problem areas in design and manufacture and assigned to appropriate design and manufacturing personnel. To a great extent, vehicle design has been effected by the organizational arrangement of the design responsible agency, laboratory, division, etc. In this manner, test and checkout operations which were administered by groups separate from the design and manufacturer evolved in the same manner; i.e.,as a separate or "tack-on" system or requirements.

Both the Saturn Apollo Applications Program and the Voyager program have mission requirements amenable to progressive implementation of OCDMS. The major question is: "Do these mission requirements justify implementation of OCDMS?"

We are basically talking about an integrated, computer-operated, on-board checkout and data management subsystem which possesses a large degree of control capability implicit in its operation. This subsystem would be implemented with back-up control and monitoring equipment or alternate-mode-of-operation system provisions using one, or more than one, or multi-mode didital machines.

Implementation of such a system requires an interfacing standardization methodology or program with all other vehicle and support subsystems to a degree never heretofore realized. Items of great significance include:

1. Design for checkout starting with preliminary design of hardware.

2. Explicit test point selection criteria.

3. Explicit test objectives and requirements criteria.

4. An optimization of the OCDMS and supporting equipment capabilities and resources allocation.

5. Only through the use of OCDMS systems after launch can extensive ground based alternate modes of operation be selected, data compression techniques changed in accord with unexpected mission events, measuring programs be changed in consequence of malfunction of transducers or to provide additional measurements not anticipated at the time of launch but found to be desirable during flight as a consequence of evaluating the regular measuring program. Only OCDMS will provide opportunities for progressive implementation of multiple redendancy, alternate mode, or adaptable systems design.

6. Above all, OCDMS can serve as a means of systems integration that can overcome organizational barriers to integrated functional design.

V. Recommendations

Onboard Checkout and Data Management Systems will find application in future space vehicle systems.

The particular system into which OCDMS is implemented will depend on whether or not the reliability contribution and increased performance or capability contribution justifies that implementation in terms of program cost, scheduling, and technical development requirements. On the basis of information gathered to date, as discussed in this report, progressive implementation of Onboard Checkout and Data Management Systems into Voyager and Saturn Apollo applications programs vehicles should prove benefical to these systems reliability and performance capabilities.

OCDMS Systems are new and unique in that they represent a vehicle sub-system serving as a "manager system". Their functioning in the total vehicle system is unique in that the system serves as an agent of coordination, support, control, and evaluation.

OCDMS Systems are further unique in that they can be considered as "compound systems". By "compound systems" we mean a system whose function is not orientented for a single operation but for a multiplicity of operations. The OCDMS system configuration can be changed in order to support such diverse operations as Post Manufacturing Checkout, In-Flight Control, or Orbital Checkout of a payload subsystem prior to which ejection for landing.

It is recommended that efforts in the area of Onboard Checkout and Data Management Systems be continued with the specific objective of developing a candidate system for use on vehicle systems scheduled for operation in the early 1970s. It is recommended that a significant effort be undertaken to design, install, and operate an Onboard Checkout and Data Management Systems Development facility and and supporting programs in order to:

1. evaluate the capabilities and effectiveness of OCDMS implementable with presently technology

2. identify and develop design, manufacturing, checkout and management intergration techniques for evolving an operational OCDMS on programs presently assigned to MSFC

3. identify deficient technology are areas and to initiate programs to fill these areas in a timely manner in light of assigned vehicle program milestones

4. implement an evolving program of developing of OCDMS sub-systems capable of supporting presently anticipated and future mission assignments to MSFC.